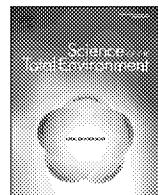




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Field-based method for evaluating the annual maximum specific conductivity tolerated by freshwater invertebrates*

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may give misleading results due to lags in biological response. This method can be used anywhere with sufficient data to estimate the temporal variability and may be applicable for field-based criteria other than the specific conductivity criteria illustrated here.

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- Barbour, M.T., Gerritsen, J., Snyder, B.D., Stribling, J.B., 1999. In: 2nd ed. (Ed.), Rapid Bioassessments Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates, and Fish. U.S. Environmental Protection Agency, Office of Water, Washington, DC EPA/841/B 99/002. <https://www3.epa.gov/region1/npdes/merrimackstation/pdfs/ar/AR-1164.pdf>.
- Bernhardt, E.S., Lutz, B.D., King, R.S., Fay, J.P., Carter, C.E., Helton, A.M., Campagna, D., Amos, J., 2012. How many mountains can we mine? Assessing the regional impact of surface mining on freshwater ecosystems of the Central Appalachians. *Environ. Sci. Technol.* 46, 8115–8122.
- Buchwalter, D.B., Clements, W.H., Luoma, S.N., 2017. Modernizing water quality criteria in the United States: A need to expand the definition of acceptable data. *Environ. Toxicol. Chem.* 36 (2):285–291. <https://doi.org/10.1002/etc.3654>.
- Cafiedo-Arguilles, M., Kefford, B.J., Piscart, C., Prat, N., Schafer, R.B., Schulz, C.-J., 2013. Salinization of rivers: an urgent ecological issue. *Environ. Pollut.* 173, 157–167.
- CCME, 2007. Canadian Environmental Quality Guidelines. Canadian Council of Ministers of the Environment <http://ceqg.rcqe.ccme.ca/en/index.html>.
- Clements, W.H., Kotalik, C., 2016. Effects of major ions on natural benthic communities: an experimental assessment of the U.S. Environmental Protection Agency aquatic life benchmark for conductivity. *Freshw. Sci.* 35, 126–138.
- Cormier, S.M., 2017a. Data for: Field-based methods for evaluating the annual maximum specific conductivity tolerated by freshwater invertebrates. 10.23719/1371704.
- Cormier, S.M., 2017b. Data for: A field-based model of the relationship between extirpation of salt-intolerant benthic invertebrates and background conductivity. 10.23719/1371704.
- Cormier, S.M., Suter, G.W., 2013. A method for deriving water-quality benchmarks using field data. *Environ. Toxicol. Chem.* 32 (2), 255–262.
- Cormier, S.M., Suter, G.W., Zheng, L., 2013a. Derivation of a benchmark for freshwater ionic strength. *Environ. Toxicol. Chem.* 32 (2), 263–271.
- Cormier, S.M., Wilkes, S.P., Zheng, L., 2013b. Relationship of land use and elevated ionic strength in Appalachian watersheds. *Environ. Toxicol. Chem.* 32 (2), 296–303.
- Cormier, S.M., Zheng, L., Flaherty, C.M., 2017. A field-based model of a relationship between extirpation of salt-intolerant benthic invertebrates and background conductivity. *Sci. Total Environ.* (this issue).
- Cummins, K.W., Klug, M.J., 1979. Feeding ecology of stream invertebrates. *Annu. Rev. Ecol. Syst.* 10, 147–172.
- Dunlop, J.E., Mann, R.M., Hobbs, D., Smith, R.E.W., Nanjappa, V., Vardy, S., Vink, S., 2015. Assessing the toxicity of saline waters: the importance of accommodating surface water ionic composition at the river basin scale. *Australas. Bull. Ecotoxicol. Environ. Chem.* 2, 1–15.
- Environment Canada, Health Canada, 2001. Priority substances list assessment report: road salts. Canadian Environmental Protection Act, 1999. <http://www.prweb.com/profiles/2008/02/07/370423/EnvironmentCanadaReport.pdf>.
- Erickson, R.J., Stephan, C.E., 1988. Calculation of the Final Acute Value for Water Quality Criteria for Aquatic Organisms. U.S. Environmental Protection Agency, Duluth, MN EPA/600/3-88-018. <https://nepis.epa.gov/Exe/ZyPDF.cgi/P100QjZ6.PDF?Dockey=P100QjZ6.PDF>.
- Erickson, R.J., Mount, D.R., Highland, T.L., Hockett, J.R., Hoff, D.J., Jenson, C.T., Norberg-King, T.J., Peterson, K.N., 2017. The acute toxicity of major ion salts to *Ceriodaphnia dubia*. II. Empirical relationships in binary salt mixtures. *Environ. Toxicol. Chem.* 36 (6), 1525–1537.
- European Commission, 2011. Common Implementation Strategy for the Water Framework Directive (2000/60/EC), Guidance Document No. 27, Technical Guidance for Deriving Environmental Quality Standards. Technical Report – 2011-055. European Communities, Brussels, Belgium <https://circabc.europa.eu/sd/a/0cc3581b-5f65-4b61-91c6-433a1e947838/TGD-EQS%20CIS-WFD%2027%20EC%202011.pdf>.
- Findlay, S.E., Kelly, V.R., 2011. Emerging indirect and long-term road salt effects on ecosystems. *Ann. N. Y. Acad. Sci.* 1223:58–68. <https://doi.org/10.1111/j.1749-6652.2010.05942.x>.
- Fritz, K.M., Fulton, S., Johnson, B.R., Barton, C.D., Jack, J.D., Word, D.A., Burke, R.A., 2010. Structural and functional characteristics of natural and constructed channels draining a reclaimed mountaintop removal and valley fill coal mine. *J. N. Am. Benthol. Soc.* 29, 673–689.
- Gerritsen, J., Zheng, L., Burton, J., Boschen, C., Wilkes, S., Ludwig, J., Cormier, S., 2010. Inferring Causes of Biological Impairment in the Clear Fork Watershed, West Virginia. National Center for Environmental Assessment, Washington, DC <http://cfpub.epa.gov/necca/cfn/recorddisplay.cfm?deid=201963>.
- Gillis, P., 2011. Assessing the toxicity of sodium chloride to the glochidia of freshwater mussels: implications for salinization of surface waters. *Environ. Pollut.* 159 (6), 1702–1708.
- Griffith, M.B., 2014. Natural variation and current reference for specific conductivity and major ions in wadeable streams of the coterminous U.S. *Freshw. Sci.* 33 (1), 1–17.
- Hershey, A.E., Lamberti, G.A., Chaloner, D.T., Northington, R.M., 2010. Aquatic insect ecology. In: Thorp, J.H., Covich, A.P. (Eds.), *Ecology and Classification of North American Freshwater Invertebrates*. Elsevier, Inc., Burlington, MA, pp. 659–694.
- Higgins, C., Wilde, G., 2005. The role of salinity in structuring fish assemblages in a prairie stream system. *Hydrobiologia* 549, 197–203.
- Johnson, B.J., Johnson, M.K., 2015. An evaluation of a field-based aquatic life benchmark for specific conductance in Northeast Minnesota. Prepared for Water Legacy. [http://waterlegacy.org/sites/default/files/u42412/Ex.16_JohnsonMNConductivityEvaluationRpt%26Attachments\(Nov.202015\).pdf](http://waterlegacy.org/sites/default/files/u42412/Ex.16_JohnsonMNConductivityEvaluationRpt%26Attachments(Nov.202015).pdf).
- Johnson, R.C., Jin, H.-S., Carreiro, M.M., Jack, J.D., 2013. Macroinvertebrate community structure, secondary production and trophic-level dynamics in urban streams affected by non-point-source pollution. *Freshw. Biol.* 58, 843–857.
- Karatayev, A., Miller, T.D., Burlakova, L., 2012. Long-term changes in unionid assemblages in the Rio Grande, one of the World's top 10 rivers at risk. *Aquat. Conserv.* 22, 206–219.
- Kaushal, S.S., Groffman, P.M., Likens, G.E., Belt, K.T., Stack, W.P., Kelly, V.R., Band, L.E., Fisher, G.T., 2005. Increased salinization of fresh water in the northeastern United States. *Proc. Natl. Acad. Sci. U. S. A.* 102:13517–13520. <https://doi.org/10.1073/pnas.0506414102>.
- Kaushal, S.S., Likens, G.E., Utz, R.M., Pace, M.L., Grese, M., Yepsen, M., 2013. Increased river alkalization in the Eastern U.S. *Environ. Sci. Technol.* 47 (18):10302–10311. <https://doi.org/10.1021/es401046s>.
- Kefford, B.J., Papas, P.J., Metzeling, L., Nugegeda, D., 2004. Do laboratory salinity tolerances of freshwater animals correspond with their field salinity? *Environ. Pollut.* 129 (3), 355–362.
- Kefford, B.J., Hickey, G.L., Gasith, A., Ben-David, E., Dunlop, J.E., Palmer, C.G., Allan, K., Choy, S.C., Piscart, C., 2012. Global scale variation in the salinity sensitivity of riverine macroinvertebrates: eastern Australia, France, Israel and South Africa. *PLoS One* 7, e35224. <https://doi.org/10.1371/journal.pone.0035224>.
- Kunz, J.L., Conley, J.M., Buchwalter, D.B., Norber-King, T.J., Kemble, N.E., Wang, N., Ingersoll, C.G., 2013. Use of reconstituted waters to evaluate effects of elevated major ions associated with mountaintop coal mining on freshwater invertebrates. *Environ. Toxicol. Chem.* 32 (12), 2826–2835.
- Lindberg, T.T., Bernhardt, E.S., Bier, R., Helton, A.M., Merola, R.B., Vengosh, A., Di Giulio, R.T., 2011. Cumulative impacts of mountaintop mining on an Appalachian watershed. *Proc. Natl. Acad. Sci.* 108 (52), 20920–20934.
- Mebane, C.A., Eakins, R.J., Fraser, B.G., Adams, W.J., 2015. Recovery of a mining damaged stream ecosystem. *Elem. Sci. Anth.* 3:42. <https://doi.org/10.12952/journal.elementa.000042>.
- Merriam, E.R., Petty, J.T., Merovich, G.T., Fulton, J.B., Strager, M.P., 2011. Additive effects of mining and residential development on stream conditions in a central Appalachian watershed. *J. N. Am. Benthol. Soc.* 30 (2), 399–418.
- Mount, D.R., Erickson, R.J., Highland, T.L., Hockett, J.R., Hoff, D.J., Jenson, C.T., Norberg-King, T.J., Peterson, K.N., Polaski, Z.M., Wisniewski, S., 2016. The acute toxicity of major ion salts to *Ceriodaphnia dubia*: I. Influence of background water chemistry. *Environ. Toxicol. Chem.* 35 (12), 3039–3057.
- Omernik, J.M., 1987. Ecoregions of the conterminous United States. *Ann. Assoc. Am. Geogr.* 77, 118–125.
- Palmer, M.A., Bernhardt, E.S., Schlesinger, W.H., Eshleman, K.N., Foufoula-Georgiou, E., Hendryx, M.S., Lemly, A.D., Likens, G.E., Loucks, O.L., Power, M.E., White, P.S., Wilcock, P.R., 2010. Science and regulation. Mountaintop mining consequences. *Science* 327 (5962):148–149. <https://doi.org/10.1126/science.1180543>.
- Pond, G.J., 2010. Patterns of Ephemeroptera taxa loss in Appalachian headwater streams (Kentucky, USA). *Hydrobiologia* 641, 185–201.
- Pond, G.J., Passmore, M.E., Borsuk, F.A., Reynolds, L., Rose, C.J., 2008. Downstream effects of mountaintop coal mining: comparing biological conditions using family and genus level macroinvertebrate bioassessment tools. *J. N. Am. Benthol. Soc.* 27 (3), 717–737.
- Pond, G.J., Passmore, M.E., Pointon, N.D., Felbinger, J.K., Walker, C.A., Krock, K.J., Fulton, J.B., Nash, W.L., 2014. Long-term impacts on macroinvertebrates downstream of reclaimed mountaintop mining valley fills in central Appalachia. *Environ. Manag.* 54 (4), 919–933.
- R Development Core Team, 2011. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria <http://www.R-project.org>.
- Stephan, C.E., Mount, D.J., Hansen, D.J., Gentile, J.R., Chapman, G.A., Brungs, W.A., 1985. Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses. U.S. Environmental Protection Agency, Duluth, MN PB85-227049. <https://www.epa.gov/sites/production/files/2016-02/documents/guidelines-water-quality-criteria.pdf>.
- Stoddard, J.L., Larsen, D.P., Hawkins, C.P., Johnson, R.K., Norris, R.H., 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. *Ecol. Appl.* 16 (4), 1267–1276.
- Suter, G.W., Cormier, S.M., 2013. A method for assessing the potential for confounding applied to ionic strength in central Appalachian streams. *Environ. Toxicol. Chem.* 32 (2), 288–295.
- Timpano, A., Schoenholz, S., Zipper, C., Soucek, D., 2011. Levels of Dissolved Solids Associated With Aquatic Life Effects in Headwater Streams of Virginia's Central Appalachian Coalfield Region. Report Prepared for the Virginia Department of Environmental Quality; Virginia Department of Mines, Minerals, and Energy; and the Powell River Project. Virginia Tech, Blacksburg, VA http://www.prp.cses.vt.edu/Research_Results/Timpano_TDSReport_2011.pdf.
- Timpano, A.J., Schoenholz, S.H., Soucek, D.J., Zipper, C.E., 2015. Salinity as a limiting factor for biological condition in mining-influenced central Appalachian headwater streams. *J. Am. Water Resour. Assoc.* 51 (1):240–250. <https://doi.org/10.1111/jawr.12247>.
- USEPA, 2011a. The Effects of Mountaintop Mines and Valley Fills on Aquatic Ecosystems of the Central Appalachian Coalfields. U.S. Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment, Washington, DC EPA/600/R 09/138F. <https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100E3KG.txt>.
- USEPA, 2011b. A Field-based Aquatic Life Benchmark for Conductivity in Central Appalachian Streams. U.S. Environmental Protection Agency, Office of Research and

Please cite this article as: Cormier, S.M., et al., Field-based method for evaluating the annual maximum specific conductivity tolerated by freshwater invertebrates, *Sci Total Environ* (2018), <https://doi.org/10.1016/j.scitotenv.2018.01.136>

- Development, National Center for Environmental Assessment, Washington, DC EPA/600/R-10/023F. <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=233809>.
- USEPA, 2012. Recreational Water Quality Criteria. U.S. Environmental Protection Agency, Office of Water, Washington, DC Office of Water 820-F-12-058, <https://www.epa.gov/sites/production/files/2015-10/documents/rwqc2012.pdf>.
- USEPA, 2013. Primary Distinguishing Characteristics of Level III Ecoregions of the Continental United States. U.S. Environmental Protection Agency ftp://ftp.epa.gov/wed/ecoregions/us/Eco_Level_III_descriptions.doc.
- USEPA, 2016. Public Review Draft: Field-based Methods for Developing Aquatic Life Criteria for Specific Conductivity. U.S. Environmental Protection Agency, Office of Water, Washington, DC EPA-822-R-07-010. Available online at: <https://www.epa.gov/wqc/draft-field-based-methods-developing-aquatic-life-criteria-specific-conductivity>.
- van Vlaardingen, P.L.A., Verbruggen, E.M.J., 2007. Guidance for the Derivation of Environmental Risk Limits Within the Framework of 'International and National Environmental Quality Standards for Substances in the Netherlands' (INS). RIVM report 601782001/2007. National Institute for Public Health and the Environment, Bilthoven, the Netherlands <http://www.rivm.nl/dsresource?objectid=7b0fb80c-5933-4fa1-b11f-dc077592fd2&type=org&disposition=inline>.
- Vander Laan, J.J., Hawkins, C.P., Olson, J.R., Hill, R.A., 2013. Linking land use, in-stream stressors, and biological condition to infer causes of regional ecological impairment in streams. *Freshw. Sci.* 32, 801–820.
- Wang, N., Dorman, R.A., Ingersoll, C.G., Hardest, D.K., Brumbaugh, W.G., Hammer, E.J., Bauer, C.R., Mount, D.R., 2016. Acute and chronic toxicity of sodium sulfate to four freshwater organisms in water-only exposures. *Environ. Toxicol. Chem.* 35, 115–127.
- Wang, N., Ivey, C.D., Ingersoll, C.G., Brumbaugh, W.G., Alvarez, D., Hammer, E.J., Bauer, C.R., Augspurger, T., Raimondo, S., Barnhart, M.C., 2017. Acute sensitivity of a broad range of freshwater mussels to chemicals with different modes of toxic action. *Environ. Toxicol. Chem.* 36 (3), 786–796.
- Warne, M., Batley, G.E., van Dam, R.A., Chapman, J.C., Fox, D.R., Hickey, C.W., Stauber, J.L., 2015. Revised Method for Deriving Australian and New Zealand Water Quality Guideline Values for Toxicants. Prepared for the Council of Australian Government's Standing Council on Environment and Water (SCEW). Department of Science, Information Technology and Innovation, Brisbane, Queensland <https://publications.csiro.au/rpr/download?pid=csiro:EP159161&dsid=D84> (43 pp).
- Woods, A.J., Omernik, J.M., Brown, D.D., 1996. Level III and IV Ecoregions of Pennsylvania and the Blue Ridge Mountains, the Central Appalachian Ridge and Valley, and the Central Appalachians of Virginia, West Virginia, and Maryland. U.S. Environmental Protection Agency, National Health and Environmental Effects Research Laboratory, Corvallis, OR EPA/600/R-96/077. <http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=91024W05.TXT>.
- Woods, A.J., Omernik, J.M., Brown, D.D., 1999. Level III and IV Ecoregions of Delaware, Maryland, Pennsylvania, Virginia, and West Virginia. U.S. Environmental Protection Agency, National Health and Environmental Effects Research Laboratory, Corvallis, OR https://extension.um.edu/sites/default/files/_docs/programs/master-gardeners/Natives/1999_Woods_Omernik_Reg3_ecoregion_descriptions.pdf.
- WVDEP, 2006. Quality Assurance Project Plan for Watershed Branch Monitoring Activities. West Virginia Department of Environmental Protection, Division of Water and Waste Management, Charleston, WV http://www.dep.wv.gov/WWE/watershed/Documents/2005_06_SOP_Ali.pdf.
- WVDEP, 2008a. West Virginia Integrated Water Quality Monitoring and Assessment Report. West Virginia Department of Environmental Protection, Charleston, VA http://www.dep.wv.gov/WWE/watershed/IR/Documents/IR_2008_Documents/WV_IR_2008_Report_Only_EPA_Approved.pdf.
- WVDEP, 2008b. 2008 Standard Operating Procedures. vol. 1. West Virginia Department of Environmental Protection, Watershed Assessment Branch, Charleston, WV.
- WVDEP, 2013. Watershed Assessment Branch 2013 Standard Operating Procedures. West Virginia Department of Environmental Protection, Charleston, VA Available online at: <http://www.dep.wv.gov/WWE/watershed/Pages/WBSOPs.aspx> (443 pp).
- WVDEP, 2015. Watershed Assessment Branch 2015 Field Sampling Standard Operating Procedures. West Virginia Department of Environmental Protection, Division of Water and Waste Management, Watershed Assessment Branch, Charleston, WV <http://www.dep.wv.gov/WWE/watershed/wqmmonitoring/Documents/SOP%20Doc%2015WABSOP%20WAB%20Field%20Sampling%20SOP.pdf>.
- Yang, J., Zhang, X., Xie, Y., Song, C., Sun, J., Zhang, Y., Giesy, J.P., Yu, H., 2017. Ecogenomics of zooplankton community reveals ecological threshold of ammonia nitrogen. *Environ. Sci. Technol.* 51 (5), 3057–3064.
- Zalizniak, L., Kefford, B., Nugegoda, D., 2006. Is all salinity the same? I. The effect of ionic compositions on the salinity tolerance of five species of freshwater invertebrates. *Mar. Freshw. Res.* 57, 75–82.
- Zhao, Q., Jia, X., Xia, R., Lin, J., Zhang, Y., 2016. A field-based method to derive macroinvertebrate benchmark for specific conductivity adapted for small data sets and demonstrated in the Hun-Tai River Basin, Northeast China. *Environ. Pollut.* 216:902–910. <https://doi.org/10.1016/j.envpol.2016.06.065>.
- Zielinski, R.A., Oton, J.K., Johnson, C.A., 2001. Sources of salinity near a coal mine spoil pile, north-central Colorado. *J. Environ. Qual.* 30:1237–1248. <http://www.ncbi.nlm.nih.gov/pubmed/11476501>.

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